

STM Observation of Vortex Lattice Transitions in Mesoscopic Superconductors

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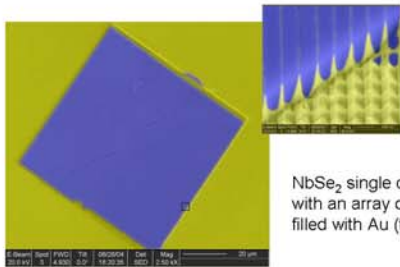
Introduction

- Scanning tunneling microscopy (STM) and spectroscopy (STS) provide information on *local density of states* in the material – essential info for nanoscience application of new electronic materials;
- STS atomic scale map of *impurity* interaction with the host materials – captures novel physics in complex systems;
- STS exposes electronic interaction at the *interface* between dissimilar materials (superconductor/ferromagnet, superconductor/semiconductor);
- Theoretically predicted novel vortex phases in mesoscopic superconductors can be visualized by STM

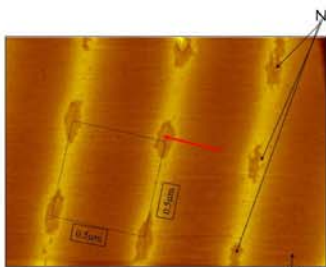
Low Temperature Scanning Tunneling Spectroscopy in Mesoscopic Superconductors

Experimental challenges:

- STM spectroscopy requires very clean and flat surfaces
- To study equilibrium effects the materials should have low intrinsic pinning

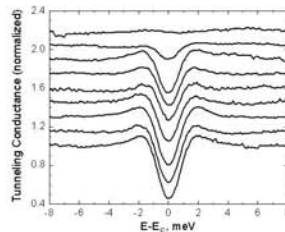


NbSe₂ single crystal surface (80 x 80 μm²) with an array of periodic submicron holes filled with Au (the surface is atomically flat)

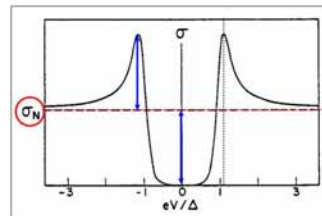


STM topography of NbSe₂ single crystal surface (2 x 1.4 μm²)

Normalized tunneling conductance taken along the red line (see above image). The superconductivity is suppressed near the hole filled with Au due to proximity effect. The core of the elliptical hole shows normal metal tunneling spectrum.



Imaging of Vortex Distribution by STM

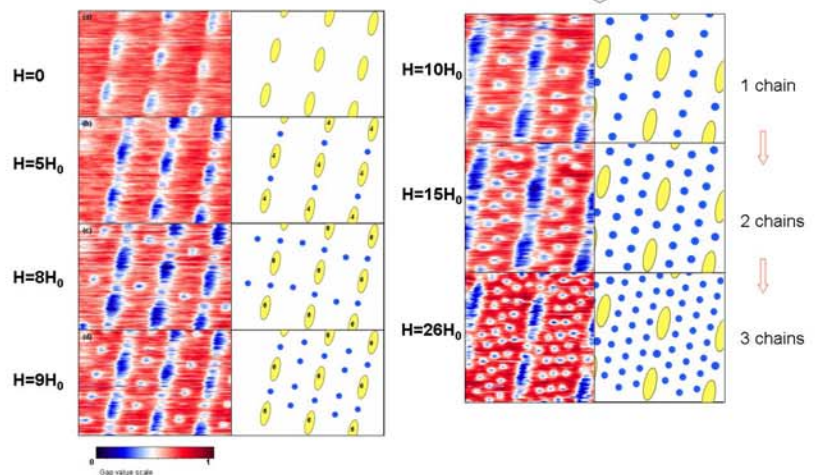


STM is an ideal tool for imaging of vortex structure in submicron superconductors since its resolution is determined by the size of the coherence length.

$$\frac{dI}{dV}(V) \propto \rho_{\text{sample}}(E_F + eV)$$

We observe co-existence of strongly interacting multi-quantum vortex lattice and interstitial Abrikosov FLL that form a composite magnetic field distribution undergoing geometrical transitions between different phase configuration states.

Geometrical Phase Transition and formation of double/triple chains



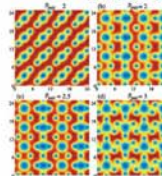
RESULTS:

- Direct imaging of the co-existent lattices of multi-quantum vortices and single quantum Abrikosov vortices
- Microscopic mechanism of topological vortex phase transitions in mesoscopic superconductors

Future Research in Mesoscopic Vortex Physics

- Creative design of hybrid systems opens new opportunities for STM/STS characterization of novel systems;
- Spatial modulation of the order parameter due to proximity of spin or exchange fields (LOFF state in clean superconductors)
- Spin orbit coupling and triplet pairing in superconductors

Vortex states in hybrid s/c –ferromagnet systems



Visualization of multi-quantum vortex-antivortex pairs induced by periodic ferromagnetic dots: red area – superconductor, blue area – vortices (large dia) and compensating antivortices (small dia) at different applied magnetic field (Priour & Fertig, PRL'04)

Relevant publication: *Phys Rev Lett* **95** 167002 (2005)